MICROWAVE RADIOMETRIC MAPPING OF OCEANOGRAPHIC AND ATMOSPHERE PARAMETERS BASED ON SATELLITE MONITORING

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ABSTRACT

The problems of processing of satellite radiophysical measurement and mapping of ocean surface and atmospheric characteristics in a monitoring regime are discussed. The principles of two-dimensional processing of multiparametric and multichannel measurements with regard to the requirements of operativeness and reliability of the monitoring system, accuracy of solution of identification and detection problems are considered. The structural solutions on organization of a real-time data processing are suggested. The importance of the development of operative methods of geophysical parameter determination in a monitoring system technology is noted. As an example of microwave radiometric data processing, we describe the computer technique used on the satellite Cosmos-1151 for measuring the atmospheric and oceanographic parameters. The estimations of accuracy of geophysical parameter determination are given.

The study of environment in global scales requires the organization of global monitoring systems. Such systems may have a complex hierarchy structure involving a satellite, earth-based receiving and data processing complexes, aeroplanes, ships etc. The operative detection and identification of anomalies (pollutions, fires, typhoons, hurricanes, tropical cyclones on the Earth's surface etc.) are regard to be one of the principle purposes of such systems.

The problem of detecting anomalies on the Earth's surface requires for its solution the application of up-to-date automatic decision machines for processing the large arrays of satellite measurements. This problem involves

the organization of in-line data processing at all detection system levels under time conditions ensuring an uninterrupted matching of operation of all cybernetic devices of the system taking into account their functional limitations (computer speed, memory capacity, etc.)

The search for anomalies on the Earth's surface involves, on the whole, the following main stages: the in-line data enters the computer in the form of m-dimensional vector T, where the number m is determined by the number of information channels and by the number of measured parameters. Then according to the computer program, statistical analysis of this information is realized by making the following two decisions: 1) storage of the landscape element features in the computer memory for accumulation of a large amount of information ("candidate"); 2) decision-making on the presence of anomaly and transmission of the anomaly information to the ground facilities.

The effectivity of the search system operation will depend, in particular, on how we construct the selection algorithm for the "suspected" landscape elements: on the one hand, the storage of these elements in the computer memory decreases its capacity for preserving current in-line data, on the other hand, roughening of the criteria of selection of suspected elements deminishes the detection probability. The solution of this contradiction lies in applying the procedure of time exhaustive search for values of separate T components as suggested in [1] . Let us consider the peculiarities of applying this procedure in problems of global detection of anomalies on the Earth's surface under monitoring conditions.

Let the entry of the monitoring system have the information going through the m channels in the form of vector $T=(t_1,\dots,t_m)$. In this case, the parallel successive procedure for estimation of value $T=T^*$ based on the successive fixation of signal values of components with the help of m successive computers is used. The simultaneous operation of all m selection devices is achieved by matching the influxes of variants of T component values. While the accepted variants are transferred from F_{i-1} to F_i the last has time to process the previous information. After F_m, the computer makes a final estimation for T with the speed v op/sec. Taking into account the computer speed V of the monitoring system at given period of time τ for estimation of T signal value we can express the condition of information influx matching in terms of the following formula:

$$V\tau = n_1 N_1 = \alpha_1 n_2 N_1 N_2 = \dots = \alpha_1 \dots \alpha_m n_m N_1 \dots N_m \frac{V}{v} \tag{1}$$

where N_i is possible number of different values of t_i, n_i is sample volume; α_i is probability of classificating t_i as a signal one.

The presence of random deviations from matching conditions in T in flux requires the buffer memory for storage of variants delaying from F_{i-1} in each device.

Two types of memory characterized by different forms of the information transfer from F_{i-1} to F are given:

1) preserving the constant variant number;
2) preserving variants for given delay time.

In work [2] were obtained the estimate of probability of an error system and wanted memory capacity with constant waiting time as well as an error system and wanted delay memory capacity with constant number of memory sells. The principle scheme considered above makes possible a complex using the different wave ranges (optical, infrared and radiorange) for the Earth's surface sensing. However, the problem concerning the realization of such scheme requires the more comprehensive consideration.

The criteria of estimation of the monitoring system effectivity lies in probability of solving of a global problem of detection and classification of phenomena on the Earth's surface. This probability depends on all complexes of parameters of a system and, in particular, on distribution of anomal signals and noises (phone).

One of the possible models of the monitoring system may be founded on the conception of "spotness" of space. As usual, the moving anomaly reserves a trace for itself which may change the spot structures and sizes. The immovable anomaly may also cause the similar local changes and be the smaller size The character of these changes depends on the relation between spot and anomaly sizes. In order to solve the problem of detecting the anomalies based on using "spots", it is necessary to have their distribution which, obviously, may be obtained only by empirical way.

Under real conditions, the study of "spots", acquisition of statistical data on them and the use of this data in a detector present difficulties. The conventional method of detecting spots is the cut-off selection method. Because of this, the spot is considered as a part of space for which the parameter of environment for given channel exceeds or does not exceed a cut-off value. The development of algorithm of spot contour description and creation of the computer program for calculating their statistic parameters

wait for further consideration.

The problems of detecting the anomalies are included into the general problem of mapping according to data on microwave sensing the Earth's surface The recognition of homogeneous formation contours and the determination of geophysical characteristics may be carried out by microwave radiometry. Therefore the development of new methods of automatic data processing from satellite and fixing the measurements on the surface are required.

After satellite K flights, we obtain the sample from K - ξ processes for two-dimensional processing. Here ξ flights are excluded from studing as no having useful information. The knowledge of each flight course using the two-dimensional correlation analysis and interpolation method permit us to make and print a map of radiobrightness temperature which may be used directly when observing different phenomena on the Earth's surface. The simpliest algorithm of making such map by a computer is determined in the following way.

Let $W^{(i)}=\{\varphi^{(i)}, W_1^{(i)}, W_2^{(i)}, \dots, W_{\omega-1}^{(i)}, W_\omega^{*(i)}, t_\omega^{(i)}, W_{\omega+1}^{(i)}, \dots, W_\mu^{(i)}\}$ be a vector of registration data of i flight, where $W_\omega^{*(i)}$ is reper object response; $t_\omega^{(i)}$ is flight time moment over reper object; $\varphi^{(i)}$ is angle between course and given constant direction; $W^{(i)}$ are measurement results

After K flights, the computer obtains matrix $\|W\|$ the lines of which are vectors $W^{(i)}$ and reduces it by removing ξ lines as no having the response from reper object or useful information.

It should be noted that for further operation $\|W\|$ lines are recorded so that the $W^{(i)}$ corresponds to $\varphi^{(i)}$ in one direction. Then on placing $\|W\|$ lines in increasing order of $\varphi^{(i)}$, the brightness temperature at the arbitrary point $M(\tau, \varphi)$ of the region being studied may be calculated according to the formula

$$W(\tau,\varphi) = W^{(i+1)} + (\varphi - \varphi^{(i+1)}) \frac{W^{(i)} - W^{(i+1)}}{\varphi^{(i)} - \varphi^{(i+1)}} \tag{2}$$

where $\varphi^{(i+1)}$ and $\varphi^{(i)}$ are the closest to φ.

There are also other algorithms of interpolation.

The development of operative methods for determining the atmosphere and underlying surface geophysical characteristics is considered to be the important aspect for construction of the monitoring system. The automatization of satellite measurement processing involves the increase of quality of mathematical methods applied. The filtration of errors on registration the telemetric signal and the estimation of accuracy of geophysical parameter measurements

are of great importance. The highest accuracy of geophysical parameter determination may be achieved by joint using the information containing in remote measurements and a priori information which may be obtained by other ways.

Some formalization possibilities of remote sensing inverse problem will be demonstrated by way of example, by processing microwave radiometric measurements from the oceanographic satellite Cosmos-1151 [5,6] . In January 1980 this satellite was launched into a circular orbit at the altitude of 650 km and a slope angle of 82,5° to equator plane. Fourchannel microwave radiometer mounted on the satellite, recorded nadir radiothermal radiation at the wavelengths of 0,8; 1,35; 3,2; 8,5 cm. In the course of present experiment there was developed the statistic method for determination of atmospheric water vapor abundance Q, liquid water content of clouds W, ocean surface temperature T_s and wind speed V at the oceans surface from microwave measurements in above mentioned channels. The method takes into account statistic properties of errors in absolute microwave measurements and available a priori information on the sought parameters.

A block diagram for automatic processing of satellite measurements is given in Fig.1. At the primary processing stage the file of telemetric readouts of the output signal in operating channels of the microwave radiometer is into a computer. The values of the signal normalized to internal calibration are determined. These normalized values are transferred to the scale of absolute brightness temperatures T_{br}. For this purpose the homogeneous earth surface regions in cloudness conditions are used as standard radiators. In parallel to T_{br} determination, the covariance matrix C of absolute measurement errors in various microwave channels is estimated by the proceedings presented in [6] . The obtained brightness temperatures are averaged according to the given space resolution, which partly makes up for the difference in antenna patterns in various channels.

At the secondary processing stage n geophysical parameters along the satellite orbit projection are determined from the obtained spectra of T_{br}. The parameters are estimated by solving the set of equations which presents the relation between geophysical parameters and T_{br} in m microwave radiometric channels:

$$\Psi(\Theta) = T + \delta T \tag{3}$$

where $\Psi(\Theta)$ is m - dimensional vector function of n - dimensional vector of geophysical parameters ; T is m - dimensional vector of the measured value T_{br}; T is m - dimensional vector of measurement errors. In solution of the inverse problem are used additional limitations to determinable parameters taking into account a priori information on permissible variation boundaries of these parameters. This makes it possible to avoid senseless values,

involved with application of, for example, the "quasistical method" (negative values of the cloud liquid water content in Fig.1,2 [7]).

As a result, the optimal value θ^* is determined by solving the extremum problem

$$\theta^* = \arg\min_{\theta \in F} \varphi(\theta, T) \qquad (4)$$

where F is the set singled out in n - space of parameters by a priori limitations. The objective function $\varphi(\theta, T)$ is constructed by the least-squares technique. In this case the value of the covariance error matrix, obtained at the primary processing stage, is used:

$$\varphi(\theta,T) = [\Psi(\theta) - T]^T C^{-1} [\Psi(\theta) - T] \qquad (5)$$

This approach enables the information provided by remote measurements and a priori data on the sought parameters to be optimally considered in the solution. The least-squares technique makes it possible to estimate the accuracy of geophysical parameter determination with due regard for noise and calibration measurement errors. The extremum problem (4) is solved by gradient methods. It does not take much machine time due to small dimension of the problem. When processing every following point of measurements, the solution obtained for the preceding point is used as zero-order approximation. This saves machine time because the values of geophysical parameters in neighbouring geographic points stand close together.

The present method has the advantage of single-valued relation between the function of $\varphi(\theta,T)$ and the density of posterior parameter distribution according to the problem (4). The value of $\varphi(\theta,T)$ at its local minimum point at F may serve as a quality criterion for the obtained solution in automatic processing. A very large value of $\varphi(\theta,T)$ indicates either a hardwave error or inadequacy of the accepted model (3). The condition may serve as a solution quality criterion [8] .

The meansquare errors in geophysical parameter determination for the present experiment are the following: Q-0,3 g/cm^2; W-0,07÷0,1 cg/m^2; V-3÷4 m/sec. The values of Ts may be determined with reasonable accuracy from measurements in radiometer nadir channels of satellite Cosmos-1151 only in the absense of foaming caused by storm. Under these conditions the mean-square error of Ts determination consititites 2-3K.

In Fig.2 is shown a latitudal distribution of Q,W, ΔV and Ts determined from measurements with satellite Cosmos-1151 over the northern part of the

Atlantic Ocean on January 25, 1980. In conformity with available models, the value of ΔV stands here for the difference between V and the critical wind speed of V_0 ($V_0 \approx 7 \div 10$ m/sec) which induces foaming. At the background of latitudal humidity distribution one can clearly see anomalous regions of Q increase caused by cloudv systems of the intertropical convergence zone (2-6 S,L) and powerful atmospheric front at 35-50 S,L. Marked anticorrelation of W and ΔV values in this front zone is due to incomplete distinction between these parameter variations in remote measurements.

For comparison, in Fig.3 are given the processing results of the sance measurements neglecting a priori limitations to parameters. It can be seen that measurement errors in this case result in the negative values of W and ΔV parameters which present difficulties for interpretation. The negative values of ΔV obtained at 2°-4°S,L and 6°-10°S,L most probably indicate the absence of foaming in these regions. In Fig.2 are given the values of Ts obtained with regard for ΔV=0 limitations. These values are in good agreement with climatic data for these regions.

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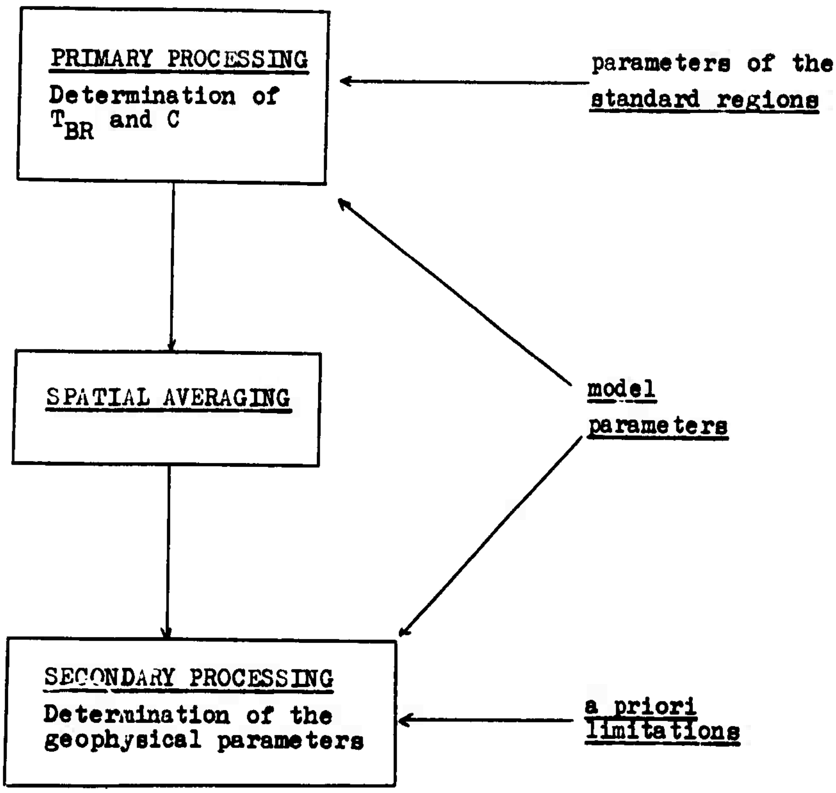

Fig.1. Automatic processing block diagram for microwave radiometric measurements from Cosmos-1151.

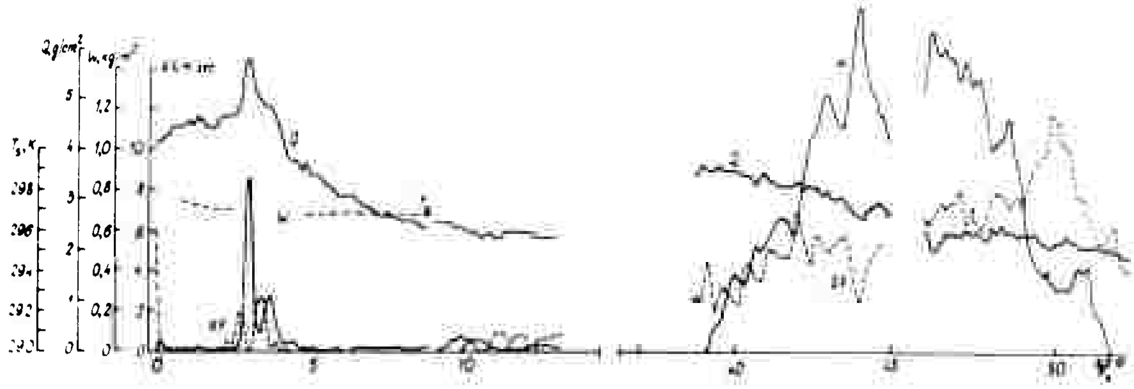

Fig.2. Latitudal distributions of Q,W, V and Ts obtained by processing satellite measurements over northern part of Atlantic Ocean on January 25, 1980.

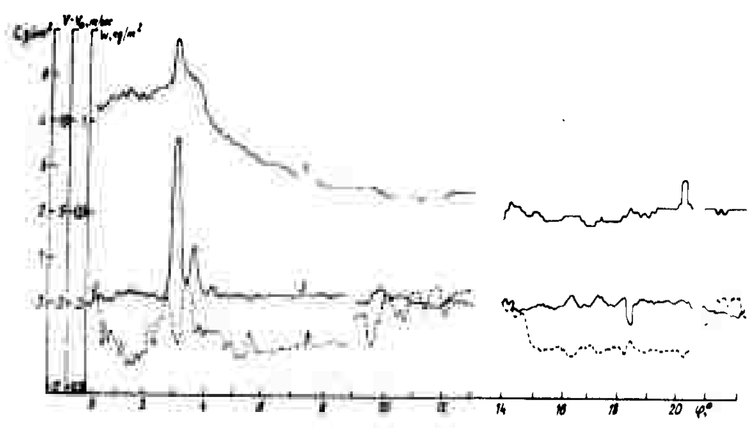

Fig.3. Latitudal distributions of Q,W, V obtained by processing the same measurements neglecting a priori information.